

# Assessing the North American Supply Chain for Traction Drive Inverters, Motors and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles

Christopher Whaling, PI

Richard Holcomb III, Manager  
Steve Johnson, Senior Researcher  
Michael Willis, Senior Policy Analyst

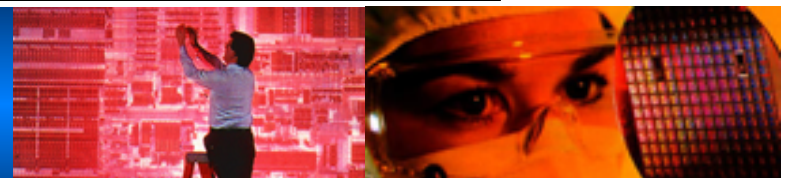
**Synthesis Partners, LLC**

For delivery Tuesday, June 19, 2018 at 8:30AM at  
US Department of Energy's Annual Merit Review (AMR) meeting.

Project ID #  
ELT089

This slide does not contain any proprietary, confidential, or otherwise restricted information.

**SYNTHESIS PARTNERS, LLC**



# Caveats

- ✓ Nothing stated in this brief is an official viewpoint of the US Department of Energy or any other official US government entity.
- ✓ Synthesis Partners makes no warranty, express or implied, nor assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed herein.
- ✓ This is an interim product and findings will change, esp. as market conditions change and new data is developed.

# Overview

## Timeline

- Start: October 2017
- End: September 2018
- Percent complete in April 2018: 50%

## Budget

- Total project funding
  - DOE share: 100%
- Funding received in FY17: \$229,959
- Funding received in FY18: \$229,959

## Barriers

- “Enable reliable hybrid electric, plug-in hybrid and range-extended electric, and battery electric vehicles with performance, safety, and costs comparable to or better than advanced conventional vehicle technologies.” (USDRIIVE Partnership Goal 1 (Nov. 2016)).
- Accurate information about Class 3-8 Electric Commercial Vehicles (ECVs) and their supply chains in North America.
- Actionable intelligence on R&D gaps that affect Autonomous Vehicles (AVs) and Class 3-8 ECV PE, batteries and motors in North America.

## Partners

### Interactions/ collaborations

- Interactions with 100s of primary sources @ OEMs, Tier 1-4s, R&D organizations & Universities.
- US DRIVE Electrical/ Electronics Technical Team members.
- NREL and ORNL (MD-HD EV Assessments)
- Project lead: Synthesis Partners, LLC

# Relevance: Progress Toward Objectives

Main focus of this update is covered below in green.

## Overall Objectives (FY18)

- ◆ Produce report on results of past (FY17) Autonomous Vehicle R&D gap analysis work.
- ◆ Targeted collection and analysis regarding the North American (NA) Class 3-8 Medium Duty-Heavy Duty (MD-HD) ECV supply chain, including batteries, inverters and motors.
- ◆ Share and collaborate with related VTO MD-HD ECV assessment activities.

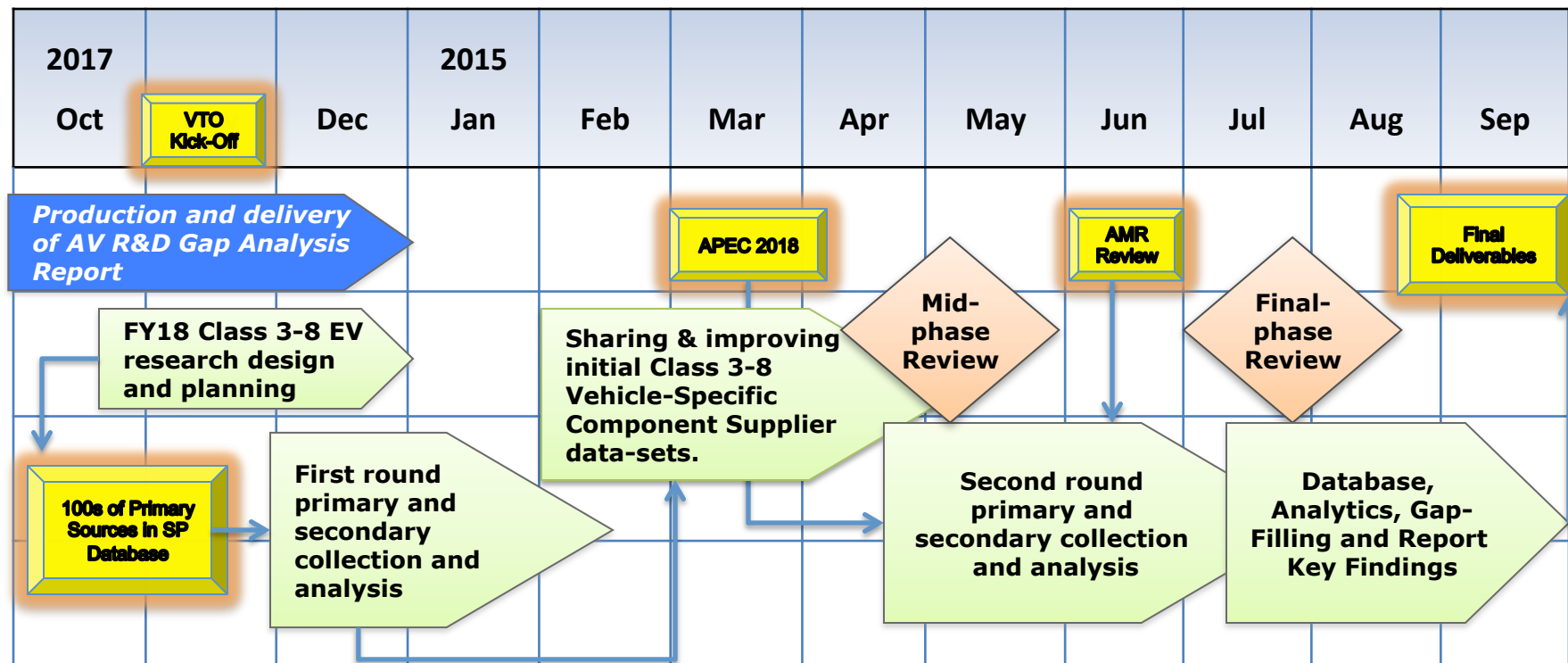
## Progress toward objectives during this period (October 2017-April 2018)

- ◆ Issued report: “R&D Gap and Trend Analysis for Autonomous and Connected Vehicles: On Connectivity, Sensors and Sensor Systems,” (November 2017). Available to the public.
- ◆ 340+ individuals contacted (Dec 2017-March 2018) to elicit information regarding NA supply chain for MD-HD vehicles and associated power electronics, motors and batteries.
- ◆ Produced initial, detailed Class 3-8 component supplier data-sets and formatted for entry into database.
- ◆ Shared data-sets with NREL and ORNL in February 2018 to collaborate on MD-HD research.

## Impact

- ◆ Independent, integrated assessment of SME views on gaps in autonomous and connected vehicle R&D domains.
- ◆ Decision support via development of comprehensive database of quantified information on NA Class 3-8 HEV, EV or PHEVs, *including vehicle-specific suppliers of batteries, inverters and motors.*
- ◆ Enabling increased accuracy and precision in analysis of NA supply chain for PE, motors, batteries, autonomous, connected and MD-HD vehicles.

# Project Milestones



**Go No/Go Decision Points:**

**Challenges/Barriers:**

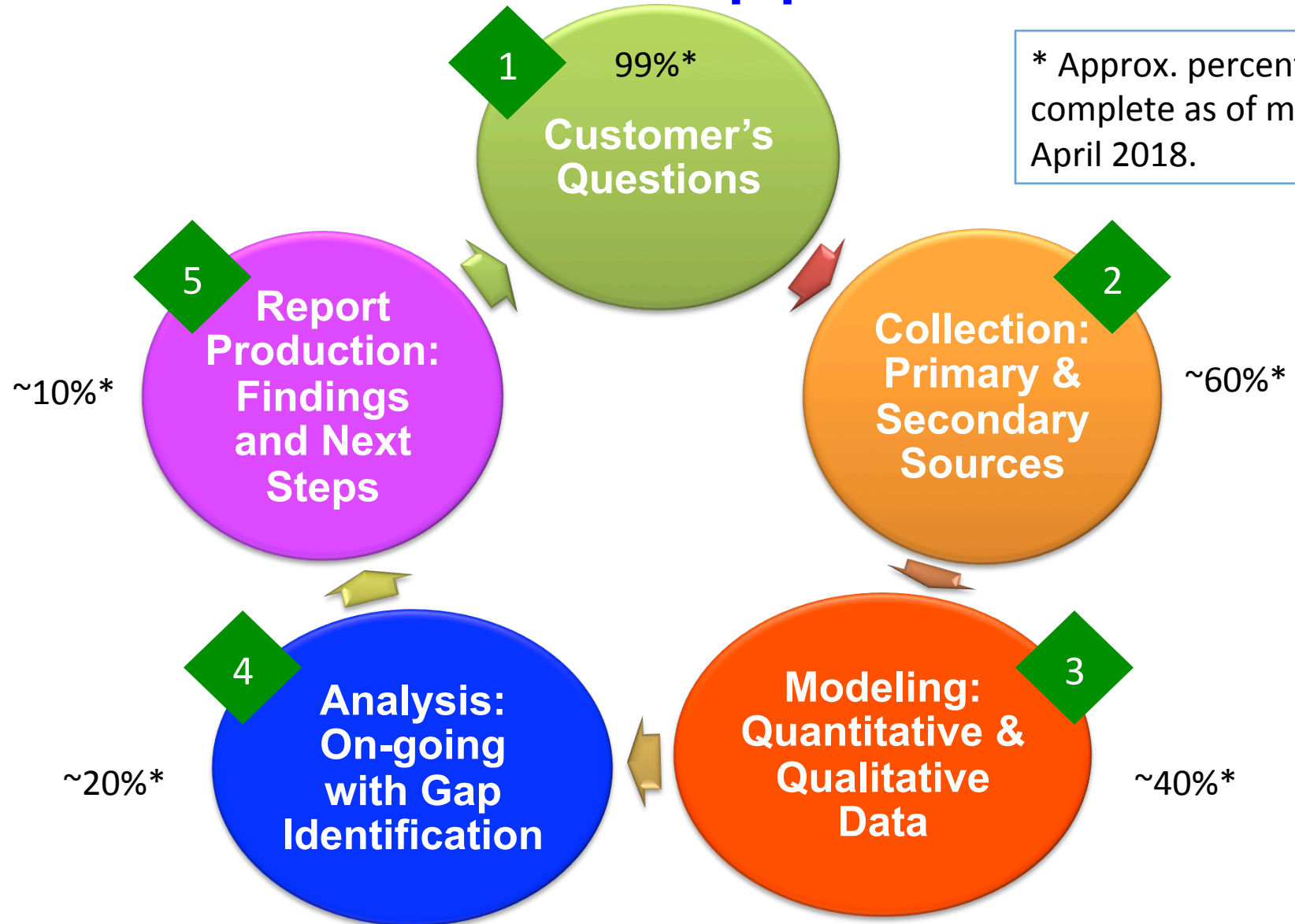
Ongoing assessment, mid- and end-of-phase review.

Time to process and analyze large amounts of heterogeneous data; accessibility of primary sources both in-person and electronically; navigation to highest-value data via source confidentiality agreements; opportunities to drill-down with SMEs on specific Class 3-8 ECV R&D gaps.

**Key Deliverables:**

Presentations, data-sets and concise report on key findings.

# Technical Approach



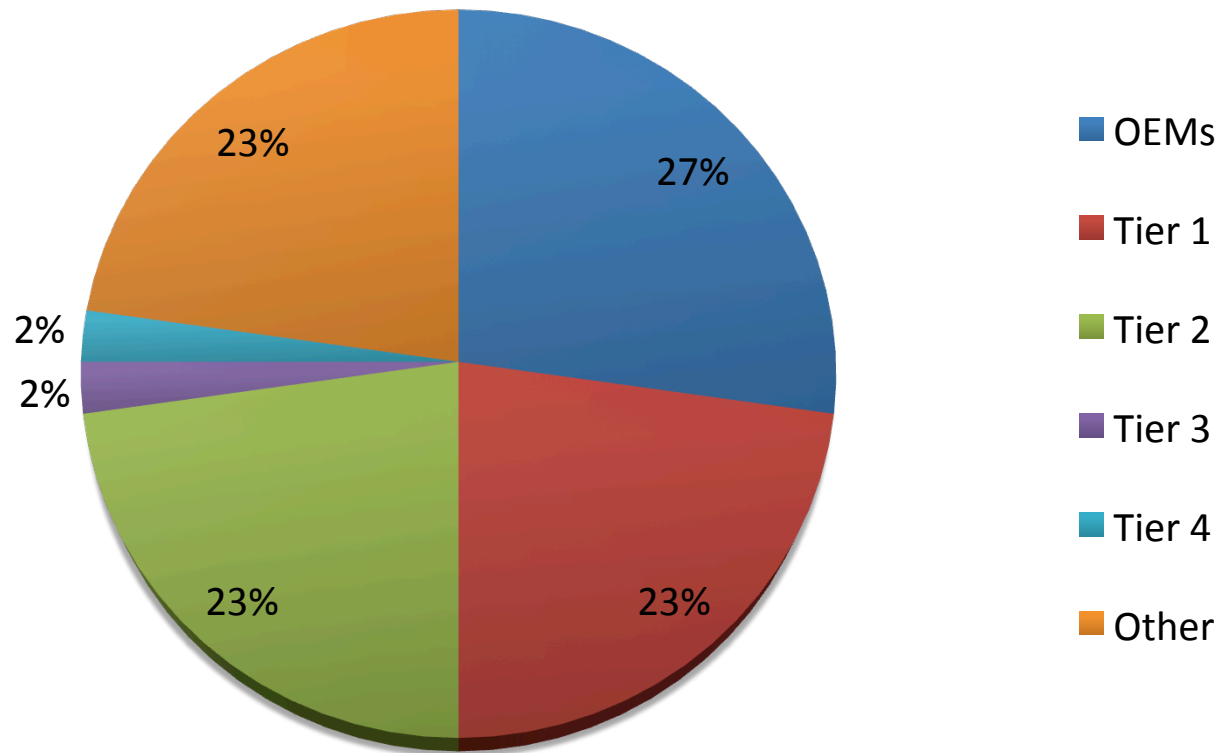
# Technical Approach Details

- **Completed December 2017:** Integrate FY17 findings and produce public report on R&D gap analysis in automated and connected vehicles. [[Public Report available.](#)]
- **Ongoing, Jan. - April 2018, main focus of these slides:** English-language primary and secondary research to develop a baseline for the most recent calendar year, of quantitative and qualitative data on:
  - i. Number, make, model, manufacturer of Class 3-8 HEV & PEV commercial vehicles on the road in North America (NA: U.S., Canada, Mexico) for the most recent full year public data is available.
  - ii. For the population of vehicles identified in #1 [a], for the same year, the suppliers of drive-train inverters, converters, motors, and batteries (which can include cells).
  - iii. Ranking of suppliers identified in #2 [b], by revenue and numbers of units shipped (as publicly available, or reasonably inferred).
- **Next step, starting in May 2018:** Employ the information and insights obtained through the above research to:
  - iv. Identify the gaps, constraints and bottlenecks in the NA supply chain for the traction drive electrification components as covered in #1-3, given the information that is available publicly and on a confidential basis.

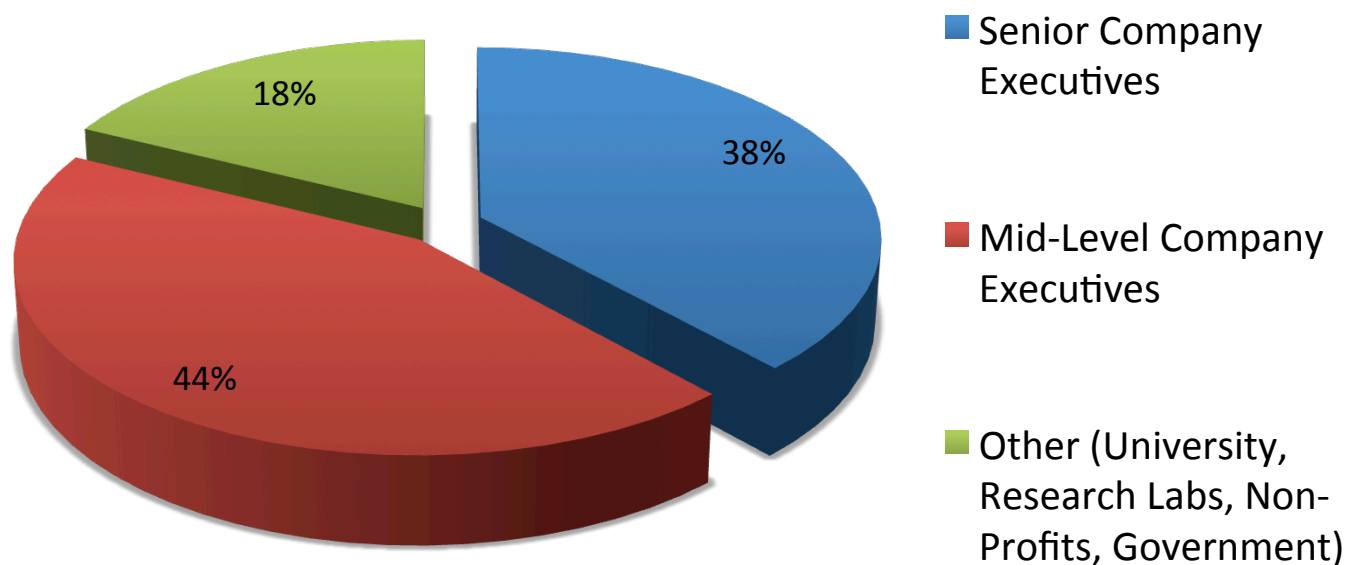
# Technical Accomplishments

- *Through mid-April 2018:*
  - *Per Approach Step #2: Collected 60% of total information we expect to collect; high value gap-filling data pending.*
  - *Per Approach Step #3: Inputted and modeled approximately 40% of the collected information into an emerging database of Class 3-8 vehicle-specific suppliers of batteries, inverters, motors and other components – focused on North America.*
  - *Per Approach Step #4: Analysis very early, just 20% complete.*
  - *Per Approach Step #5: Production phase just beginning.*
- *In-depth collection and data entry continues, while analysis and production just beginning at time of submission of these slides.*
- *Specifically, completed primary and secondary-source research includes:*
  - ✓ 500+ phone calls made and e-mails executed.
  - ✓ 1,000+ electronic sources reviewed.
  - ✓ 220 individual company or organizational contacts identified as having relevant experience or information for this project.

# Distribution of Organizational Contacts, by Type (As of April 6, 2018)



# Distribution of Primary Sources, by Organizational Role (As of April 6, 2018)



# Technical Accomplishments cont'd.

- *In progress cont'd.* (through mid-April 2018):
  - ✓ 340 individual executives identified within the 220 organizations and companies, with relevant experience or information for this project.
  - ✓ 50+ in-depth technical conversations, with SMEs in materials, components, semiconductors, vehicle electrification and related topics at APEC 2018.
  - ✓ 100+ rows in the database on supply chain and gaps (details in next slides). *Focus of next slides.*
  - ✓ More than 10 initial, gaps identified in Class 3-8 NA supply chain. Further analysis required before briefing on this gap information.

# Emerging Class 3-8 PHEV and EV Vehicle and Component NA Supply Chain Database

- Data on suppliers of motors, inverters, batteries and other components, including data on:
  1. Supplier
  2. Year of Information Sourcing
  3. Tier of Supplier (for this activity)
  4. Supplier HQ Address, Website
  5. Supplier Parent Company
  6. Supplier Main Focus
  7. Class 3-8 (MD-HD) Vehicle that the Company Supplies
  8. Years that this Class 3-8 Vehicle Was/Is/Planned to Be in Production
  9. Number of Class 3-8 Vehicles that Company Has Supplied
  10. Number of Class 3-8 Vehicles that Company Has Supplied That Are In Operation in North America (NA)
  11. ...Other data

# Emerging Class 3-8 Supplier Database

	Company	Year of Information Sourcing	Tier of Company, For this Activity	Company HQ Address	Company Website	Company Parent	Company Focus
1							
47	Caterpillar	2107	OEM	Peoria, IL	<a href="https://www.caterpillar.com">https://www.caterpillar.com</a>	Publicly-owned	mfg. heavy-duty equipment
48	Chanje Energy, Inc.	2017	OEM	Burlingame, CA	<a href="http://www.chanje.us/">http://www.chanje.us/</a>	JV between FDG (China) and Smith Electric Vehicles	mfg. electric trucks
49	Chanje Energy, Inc.	2017	OEM	Burlingame, CA	<a href="http://www.chanje.us/">http://www.chanje.us/</a>	JV between FDG (China) and Smith Electric Vehicles	mfg. electric trucks
50	Chanje Energy, Inc.	2017	OEM	Burlingame, CA	<a href="http://www.chanje.us/">http://www.chanje.us/</a>	JV between FDG (China) and Smith Electric Vehicles	mfg. electric trucks
51	Chanje Energy, Inc.	2017	OEM	Burlingame, CA	<a href="http://www.chanje.us/">http://www.chanje.us/</a>	JV between FDG (China) and Smith Electric Vehicles	mfg. electric trucks
52	Chanje Energy, Inc.	2017	OEM	Burlingame, CA	<a href="http://www.chanje.us/">http://www.chanje.us/</a>	JV between FDG (China) and Smith Electric Vehicles	mfg. electric trucks
53	Complete Coach						
54	Daimler Buses North America (DBNA)	2013	OEM	Greensboro, NC	<a href="https://daimler-trucksnorthamerica.com/">https://daimler-trucksnorthamerica.com/</a>	Daimler Trucks North America	hybrid-electric bus mfg.
55	Daimler Buses North America (DBNA)	2012	OEM	Greensboro, NC	<a href="https://daimler-trucksnorthamerica.com/">https://daimler-trucksnorthamerica.com/</a>	Daimler Trucks North America	hybrid-electric bus mfg.
56	Delphi Technologies	2012	1	London, UK	<a href="http://www.delphi.com">http://www.delphi.com</a>	Delphi	Mfg. inverters, converters, control modules for hybrid and electric propulsion systems for medium- and heavy-duty vehicles

As well as Motors, Batteries, Other Components

# Emerging Component Supplier Data

- Motors, Inverters or Batteries Supplied to Class 3-8 Vehicles
  - Example: Allison Hybrid H 40 EP and H 50 EP Drive Unit
    - 430-900 VDC 160 kW continuous 3-phase AC motor weighing 165 lbs (75 kg)
    - 3rd generation energy storage system (ESS3)
    - ESS3 uses nickel metal hydride (NiMH) battery cell technology from PEVE (f/k/a Panasonic EV Energy)
    - Class 3-8: EV and Hybrid City Buses: Gillig, New Flyer (see next slide)
- Annual Production Location, Volume or Capacity re: Class 3-8 Vehicles
  - Example: Allison (HQ: Indianapolis)
    - Allison H 40 EP & H 50 EP began production in Q4 2003
    - Allison H 3000 production scheduled to begin in Q4 2013
    - Approximately X# (*data still under development*) total hybrid propulsion systems supplied into US; with majority operating in US city transit bus applications.
- Gap or Constraint relevant to the Class 3-8 NA Supply Chain
  - Example: Tier 1
    - “Battery Life - this is a huge issue that will impact cost; Battery Disposal - need to develop an acceptable solution; Battery Charging -- need to decide if multiple approaches will continue to be pursued or if a standard approach, or at least limiting to 1-3 approaches to ensure wide-spread availability of charging options.”

# Emerging Vehicle-to-Component Data

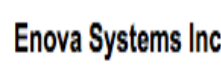
- Example: A123 (Livonia, MI)
  - *Selected components supplied:* Lithium Ion-Nickel Manganese Cobalt battery; Lithium Ion Cylindrical and Prismatic Cell Battery Packs
  - *Class 3-8 applications:* New Flyer Xcelsior XE40 Bus; BAE Systems HybriDrive Series Propulsion System; Navistar E-Star Class 3 (2010-2013); Orion VII Hybrid Electric Bus (in service since 2007); Smith Electric Class 5-7 Newton electric truck.
- Example: Allison Transmission (Indianapolis, IN)
  - *Selected components supplied:* Traction driver inverter; Allison H40/50 EP (both generator and motor).
  - *Class 3-8 Applications:* Gillig Low Floor BRT Bus (Allison EP 40/H 40 EP) (2004-present); Gillig Low Floor BRT Trolley Bus (Allison Parallel diesel-electric hybrid powertrain); Nova LFS HEV bus (H40 EP); Nova LFS Arctic HEV (H50 EP); Motor Coach Industries D4500 CT Hybrid Commuter Coach (Allison Ep50 EP).
- Example: BAE Systems (Endicott, NY)
  - *Selected components supplied:* AC traction drive induction motor; BAE HDS200 and HDS300 full series electric propulsion systems (aka BAE HybriDrive). Power flows in series from engine to generator to traction motor; alternator system; adaptable to all electric.
  - *Class 3-8 Applications:* Nova LFS HEV bus; Nova LFS Arctic HEV; Orion VII HEV bus; Gillig Low Floor Series Buses w/ diesel-electric propulsion.

# Class 3-8 HEV, EV and PHEV North American Initial Market Assessment\*

## Vehicles



## Inverters



## Batteries



## Motors



## Engineering Design



## Integrated E-Drive Systems



\* Companies can overlap across categories. This is an interim view for illustration only.

# Interim Findings

- How many Class 3-8 HEV and EV commercial vehicles are on the road in North America?
  - *27,847 and counting (covers all vehicles delivered, in use or retired, as of 2016).*  
Source: Federal Transit Authority (FTA) “Revenue Vehicle Inventory,” Baseline 2016, sorted by SP for EV and HEV wheeled vehicles only.
  - *5,774 and counting (covers vehicles in operation in NA only, does not include prototypes or retired vehicles).*  
Source: SP primary source statements, as of April 2018, covering battery EV and HEV Class 3-8 commercial vehicles in operation in North America.
- Final answer in September 2018.
  - Based on Class 3-8 vehicle models; manufacturers; date of entry; date of retirement; date of planned entry; time-in-use; and (as feasible) average lifetime miles per active vehicle model.
- Please contact Christopher Whaling at [cwhaling@synthesispartners.com](mailto:cwhaling@synthesispartners.com) with any data or information.

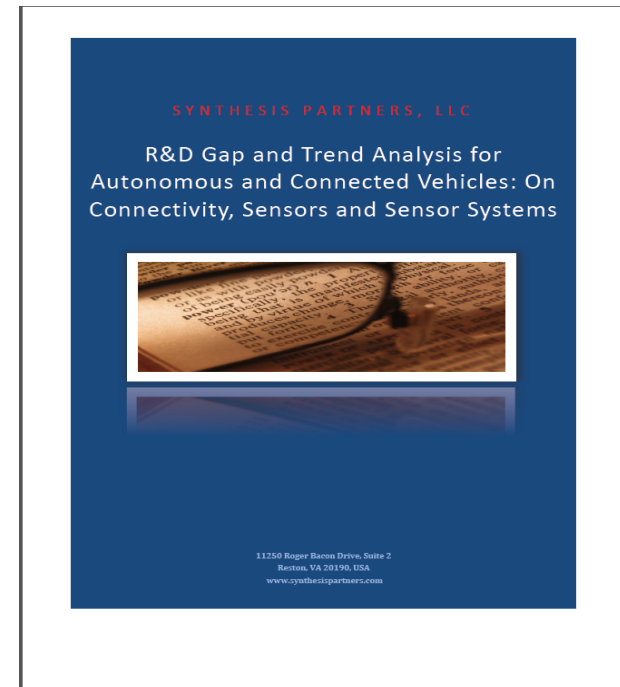
# Public Report

Based on prior year's technical research, publishing work completed in December 2017.

- Title: "R&D Gap and Trend Analysis for Autonomous and Connected Vehicles: On Connectivity, Sensors and Sensor Systems," (November 2017).

Available to the public, please request a copy from:

Christopher Whaling  
[cwhaling@synthesispartners.com](mailto:cwhaling@synthesispartners.com)

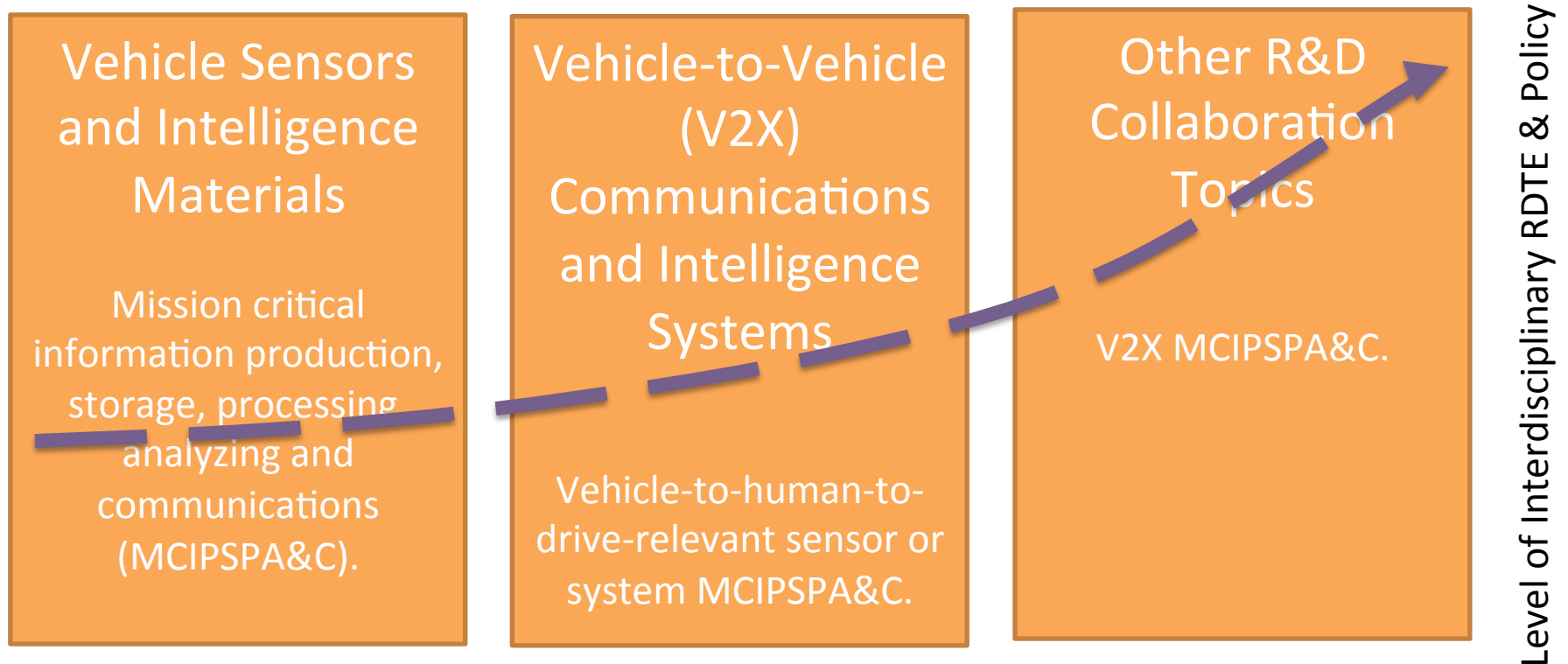


# 37 Gaps Identified in Autonomous and Connected Vehicle Research

Research on autonomous and connected vehicles research, sensors (incl. LiDAR) and sensor system developments in North America for the purpose of identifying R&D gaps that VTO may invest in.

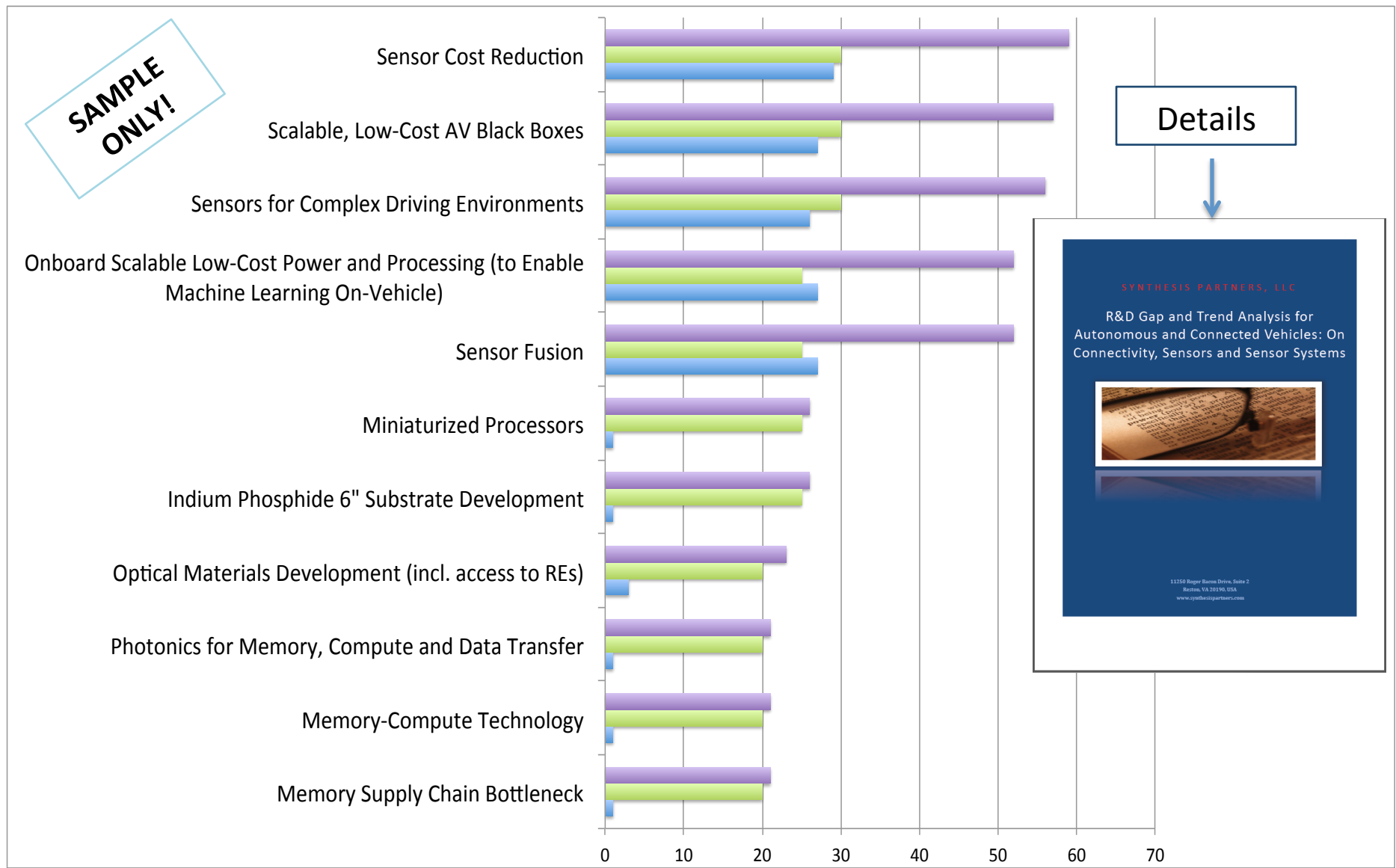
- 37 in total R&D gaps in autonomous and connected vehicle research identified as relevant to VTO interests.
- 11 of 37 Gaps identified in “Vehicle Sensors and Intelligence Materials”
  - Definition: Hardware for low-cost, high-performance, energy dense data storage, processing and communication on the vehicle; includes LiDAR gaps.
- 11 of 37 Gaps identified in “Vehicle-to-Vehicle (V2V) Communications and Intelligence Networking”
  - Definition: Hardware for low-cost, high-performance, energy dense, secure and reliable communications, sensors and sensor fusion.
- 15 of 37 Gaps identified in “Other R&D Collaboration Opportunities”
  - Definition: Policy-technology and standards development opportunities to address gaps in the autonomous vehicle and V2X (vehicle-to-anything) connectivity space.

# Gaps Increasing as Level of Interdisciplinary RDT&E Increases

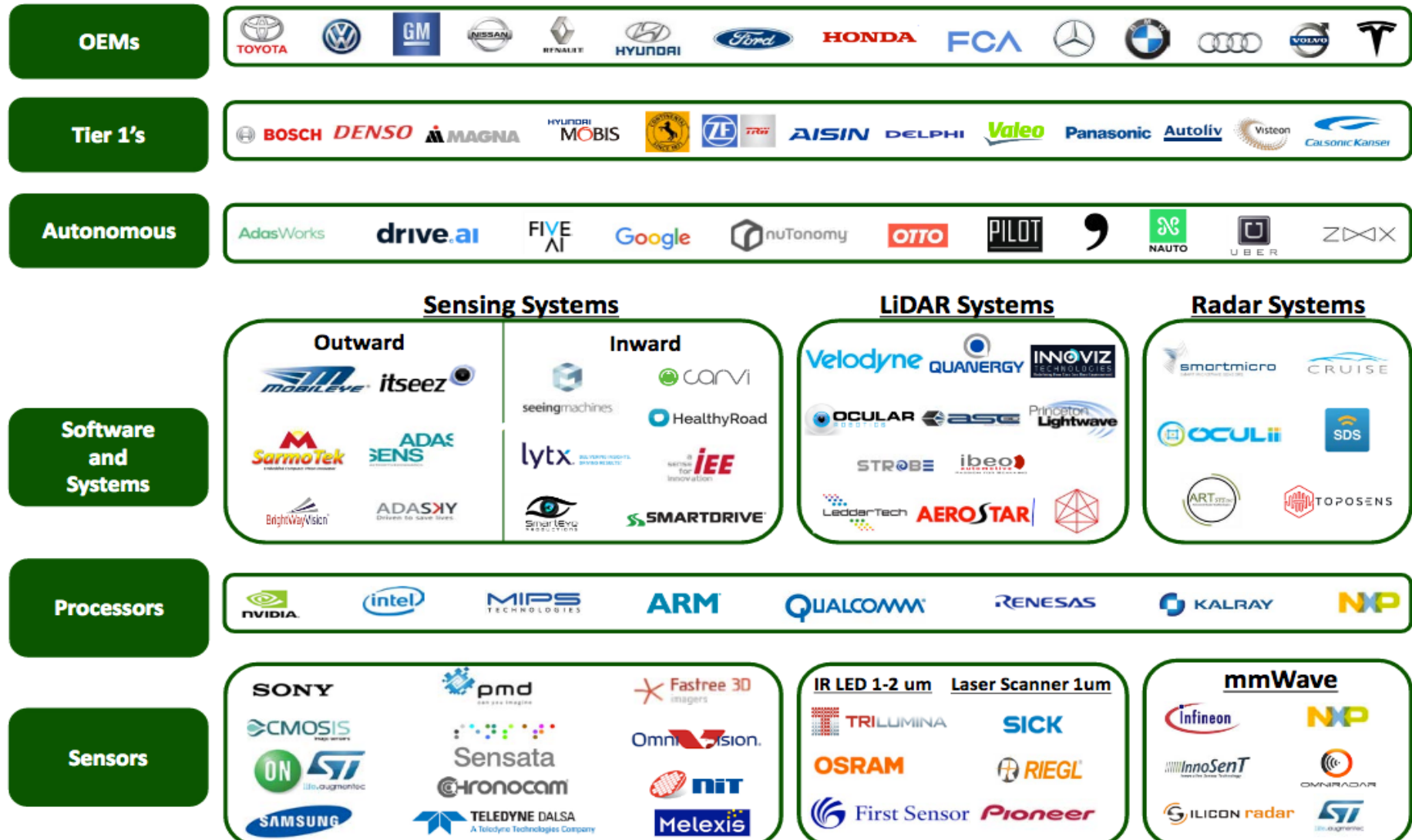


Hardware ... → Hardcoded Hardware Accelerators for Software ... → Software

# Vehicle Sensors and Intelligence Materials Gaps



# Autonomous Vehicle Players: Relevant to the Future Class 3-8 Market



# Coordination and Collaboration

- Close coordination and collaboration with 100s of industry, OEMs, Tier 1-4, universities and other subject matter experts on both public and proprietary basis.
- In-depth engagement with select sources at conferences (e.g., APEC 2018) to work to identify gaps and technology development opportunities in support of VTO and USDRIVE partnership goals.
- Engagement with DOE federal research labs, e.g.; SP shared early data-sets on MD-HD market and component suppliers with NREL and ORNL for discussion and feedback in February 2018.

# Project Summary

- Reviewer Comments: This project was not reviewed in FY17.
- FY18 research work is at mid-point at time of production of these slides.
  - Interim findings will be vetted and gaps filled via select MD-HD sources and analysts over next period.
- FY18 research is fundamentally collaborative in that it builds directly on prior and new source relationships and findings.
  - Responsibility of SP is to maintain an increasingly deep pool of researcher, OEM, Tier 1-4 and other relationships with varied, independent viewpoints, to help address VTO decision-needs and objectives.
  - Our job is to contribute to understanding “on both sides of the table” → by accessing and reporting varied, independent viewpoints and best-available data on the NA supply chain.
  - SP does everything possible to maintain open lines of communication to encourage new thinking, new ideas and a diverse range of actionable information and guidance is produced for VTO decision-makers.
- Collaboration and coordination, including with USDRIVE-EETT and VTO stakeholders, is a key ingredient to project success.

# Thank you for your interest.

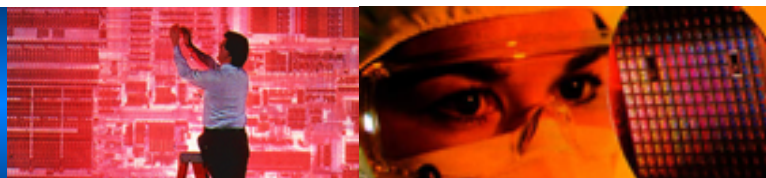
## We welcome your feedback.

POC:

PI, Christopher Whaling

Email: [cwhaling@synthesispartners.com](mailto:cwhaling@synthesispartners.com)

**SYNTHESIS PARTNERS, LLC**



# Technical Background Information

- Defining Class 3-8 Vehicles

# Vehicle Classifications

Class is determined by the gross vehicle weight rating (GVWR) of the vehicle.

## Light Duty Trucks

- Class 1 – This class of truck has a GVWR of 0 to 6,000 pounds (0 to 2,722kg).
- Class 2 – This class of truck has a GVWR of 6,001 to 10,000 pounds (2,722 to 4,536 kg).
- Class 3 – This class of truck has a GVWR of 10,001 to 14,000 pounds (4,536 to 6,350 kg).

## Medium Duty Trucks

- Class 4 – This class of truck has a GVWR of 14,001 to 16,000 pounds (6,351 to 7,257 kg).
- Class 5 – This class of truck has a GVWR of 16,001 to 19,500 pounds (7,258 to 8,845 kg).
- Class 6 – This class of truck has a GVWR of 19,501 to 26,000 pounds (8,846 to 11,793 kg).

## Heavy Duty Trucks

- Class 7 – This class of truck has a GVWR of 26,001 to 33,000 pounds (11,794 to 14,969 kg).
- Class 8 – This class of truck has a GVWR of greater than 33,001 pounds (14,969 kg), and includes all tractor trailers.

Source: "Commercial Motor Vehicle Classification", Martin Murray, 11-18-16,  
<https://www.thebalance.com/commercial-motor-vehicle-classification-2221025>; Accessed  
10-11-17.

**Class Three: 10,001 to 14,000 lbs.**



City Delivery



Mini Bus



Walk In

**Class Four: 14,001 to 16,000 lbs.**



City Delivery



Conventional Van



Landscape Utility



Large Walk In

**Class Five: 16,001 to 19,500 lbs.**



Bucket



City Delivery



Large Walk In

**Class Six: 19,501 to 26,000 lbs.**



Beverage



Rack



School Bus



Single Axle Van



Stake Body

Source: <https://www.afdc.energy.gov/data/10381>; Accessed 11/16/17.

**Class Seven: 26,001 to 33,000 lbs.**



City Transit Bus



Furniture



High Profile Semi



Home Fuel



Medium Semi Tractor



Refuse



Tow

**Class Eight: 33,001 lbs. & over**



Cement Mixer



Dump



Fire Truck



Fuel



Heavy Semi Tractor



Refrigerated Van



Semi Sleeper



Tour Bus

Source: <https://www.afdc.energy.gov/data/10381>; Accessed 11/16/17.